Energy Research and Development Division
FINAL PROJECT REPORT

ENERGY-EFFICIENT HIGH-TECH BUILDINGS

Prepared for: California Energy Commission
Prepared by: Lawrence Berkeley National Laboratory

DECEMBER 2008
CEC-500-2013-062

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Contract Number: 500-06-053

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ACKNOWLEDGEMENTS

This work was supported by the California Energy Commission, Public Interest Energy Research (PIER) program, under Contract No. 500-06-053, and by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Special thanks are extended to the Industry Partners and project participants for their support of this project.

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- Industry Partners and Other Collaborators
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  - Sun Microsystems
  - Silicon Valley Leadership Group (SVLG)
  - ISR-Spraycool
  - APC
  - Emerson-Liebert
  - Rittal
  - IBM/Vette
  - Modius
  - PowerAssure
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  - Nextek
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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The Energy Research and Development Division strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

Energy Research and Development Division funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
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- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Energy-Efficient High-Tech Buildings is the final report for the Energy Efficient High-Tech Buildings project (contract number 500-06-053) conducted by Lawrence Berkeley National Laboratory. The information from this project contributes to Energy Research and Development Division's Industrial/Agricultural/Water End-Use Energy Efficiency Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

This project focused on research and demonstrations of energy efficiency strategies for improving the energy performance of laboratories, cleanrooms, and data centers. Key results included proposed Leadership in Energy and Environmental Design criteria for use with cleanrooms or data centers; data center modular cooling system comparisons; cross-cutting efficiency strategies for high-tech buildings; collaboration on direct current power use; alternative cooling demonstrations for data centers; and collaboration with the Silicon Valley Leadership Group on data center demonstrations.

An industry committee assembled for each building type developed Proposed Leadership in Energy and Environmental Design criteria. The criteria emphasized energy and water use credits and deemphasized other sustainability credits.

Evaluations of modular cooling systems for data centers involved significant commitment from industry partners who supplied the systems for evaluation and hosted the installation in an operating data center. The study concluded that these systems perform better than standard practice.

Industry collaboration to promote the use of direct current power distribution in data centers continued following a demonstration in a prior California Energy Commission research project. This led to developing and commercializing standard direct current power connectors for use with information technology equipment and general agreement on distribution voltage.

An alternative cooling technology for use in data centers was demonstrated. This complex system involves spraying a di-electric fluid directly on components; however, significant energy savings were achieved compared to standard practice.

Lawrence Berkeley National Laboratory and the Silicon Valley Leadership Group jointly encouraged data center demonstration projects, which culminated in a data center "Summit" hosted by Silicon Valley Leadership Group where new or underutilized technologies were demonstrated.

One of the project's key recommendations is that the California Energy Commission Energy Research and Development program continues research on high-tech buildings and forms a high-tech center to continue research and development for high-tech buildings.

Keywords: California Energy Commission, high-tech buildings, data centers, DC Power, LEED criteria, modular cooling, SVLG, spray cooling, data center efficiency

Please use the following citation for this report:

Tschudi, William. (Lawrence Berkeley National Laboratory). 2008. *Energy-Efficient High-Tech Buildings.* California Energy Commission. Publication number: CEC-500-2013-062.

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EXECUTIVE SUMMARY

Introduction

To reflect the continued importance of high-tech buildings to California's economy, the Public Interest Energy Research program and Lawrence Berkeley National Laboratory initiated this project focused on selected high value research and demonstration topics applicable to laboratory, cleanroom, and data center facilities. These facilities typically operate continuously and are characterized by having large, continuous electrical demand, significant natural gas demand in many cases, and far higher energy intensities (energy per unit of floor area) than conventional buildings.

Prior investigations have consistently found energy efficiency opportunities that could result in 20-40 percent energy savings and new solutions offer the prospect of further efficiency gains.

Project Purpose

The goal of this project was to conduct research and demonstrations of energy-efficiency strategies for improving energy performance of laboratory cleanrooms and data centers in order to encourage adoption of best practices in high-tech buildings. Many high profile advancements were identified in this research project through working with industry associations such as the Silicon Valley Leadership Group, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Uptime Institute, 7 X 24 Exchange, and leading high-tech firms and their suppliers.

Project Results

Some of the more significant achievements described in this report include:

- Proposed criteria for cleanroom or data center facilities that the United States Green Building Council could consider for including in the Leadership in Energy and Environmental Design building rating system. Proposed criteria developed in this project were peer reviewed by all of the major data center organizations.
- Further development of direct current power for data centers, including standardizing distribution voltage and connectors, which are emerging as an opportunity for a worldwide standard. Over 30 companies, including European and Japanese collaborators have participated in the development to date.
- Demonstration of an alternative cooling strategy for servers illustrating the ability to cool without using mechanical cooling, such as chillers.
- Comparison of commercially available modular cooling systems used to cool racks of computers.
- Participation in the 2008 Silicon Valley Leadership Demonstration study, which culminated in a workshop attended by over 350 high-tech professionals.

- Co-leadership of the 2009 Silicon Valley Leadership Group demonstration projects, enabling a Silicon Valley Leadership Group/Public Interest Energy Research program partnership, and demonstrating leadership in the high-tech field through interaction with industry.

- Numerous training and outreach workshops were conducted at various venues in California.

- Extensive web-based publishing of results and data (http://hightech.lbl.gov), as well as articles in trade publications and professional journals.

- Active participation in industry Technical Committees or standard-setting groups including:

    - American Society of Heating, Refrigerating and Air-Conditioning Engineers.
    - 7x24 Exchange.
    - Sematech.
    - Uptime Institute.
    - Silicon Valley Leadership Group.
    - Critical Facilities Roundtable.
    - Labs 21.
    - Green Grid.
    - AFCOM.

A portion of the project was not completed during the contract period and a decision was made to terminate the work rather than extend the contract. This resulted in scaling back some tasks, with budget returned to the Public Interest Energy Research program. The major uncompleted task was organizing and reporting on pilot demonstrations of the use of direct current power in data centers due to timing difficulties with demonstration partners. In addition, activities in several other tasks were reduced. For the demonstration of direct current power, considerable efforts were made to enlist industry partners. Many direct current power industrial partners assisted Lawrence Berkeley National Laboratory in attempting to locate suitable pilot projects within new or operating data centers. Several potential projects were identified, including:

- Sonoma Mountain Village, a new data center project in Sonoma, CA to develop a sustainable community.

- Equinix, a co-location facility in San Jose.

- AT&T, which suggested a pilot demonstration in their Hayward, CA test bed facility.

- Nippon Telegraph and Telephone America, which initially expressed interest in housing a direct current pilot demonstration within a portion of a new data center under construction.
- University of California, San Diego, which was planning to install direct current infrastructure to support existing and planned renewable on-site energy sources. A commitment was made to proceed with this demonstration as part of a subsequent Public Interest Energy Research program project to be completed in 2009 or 2010, beyond the term of this contract.

The research and demonstrations conducted under this project illustrated that there are numerous energy efficiency strategies that can improve the efficiency of high-tech buildings. It is recommended that PIER continue to support research and demonstrations related to this market. Establishing a center for high-tech facility research, design and development should be considered in order to focus on these energy intensive facilities that are crucial to California's economy. Collaboration should continue with major industry organizations such as the Silicon Valley Leadership Group to accelerate adopting energy efficient strategies and technologies.

Project Benefits

This project has provided further insight into energy efficiency opportunities in cleanrooms, laboratories and data center facilities. The various technologies and demonstrations explored show there is potential for large energy savings using available best practices as well as improved performance with new solutions. Energy savings of 20 to40 percent were shown to be possible and these savings were re-affirmed by the Silicon Valley Leadership demonstrations. This project has also helped raise the awareness of California data center operators and designers.

CHAPTER 1: Introduction

Energy intensive high-tech buildings are ubiquitous in California and are the cornerstone for many industries and institutions important to the State. Biotechnology, semiconductor research, aerospace, automotive, healthcare, among others are industries that heavily rely on high-tech buildings. In addition, virtually every company operates data centers and a large computing presence exists in web based firms, banking, entertainment and other industries. Academic, defense, national laboratories, and other federal and state agencies also operate large energy intensive high-tech buildings. The energy use of these facilities is large and growing. The Public Interest Energy Research (PIER) program recognized the importance of these facilities to California and also recognized the large energy savings potential that is possible. As a result, one of the early PIER initiatives created research roadmaps to guide PIER activities.

This project continued research and demonstrations to advance the understanding of energy efficiency improvements that are available to the high-tech community. Selective research and demonstration projects supporting areas identified in the research roadmaps were completed in earlier PIER projects. These projects identified areas of large potential energy savings for these building types. The development of the roadmaps and subsequent research projects involved close collaboration with industry to identify areas of potential energy savings. There was further collaboration to demonstrate new technologies, and to identify barriers to adoption.

The project reported here included activities aimed at cleanroom and data center facilities as well as some cross-cutting strategies applicable for all high-tech buildings. The project also enabled collaboration with one of the nation's leading high-tech industry associations, the Silicon Valley Leadership Group (SVLG). In this collaboration, Lawrence Berkeley National Laboratory (LBNL) represented PIER in working with SVLG companies to develop and then publicize data center demonstration projects. LBNL participated in a data center "Summit" where the member companies, and LBNL, reported on various energy efficiency projects.

This report is organized such that each task is addressed in summary fashion in the body of the report where task numbers correspond to the contract task numbers. Detailed stand alone reports and supplemental materials for each task were prepared and are attached as appendices to this overall project report. See the Appendix summary for task and appendix number correlation. These collectively constitute the deliverables for the project.

CHAPTER 2:
Project Objectives

This project included objectives in the following areas:

- Continue to follow the PIER high-tech buildings roadmaps.
- Develop case studies and best practice information.
- Develop appropriate Leadership in Energy and Environmental Design (LEED™) type criteria for use in high-tech buildings.
- Evaluate technologies to determine their energy-efficiency.
- Dispel concerns over the use of air economizers in data centers.
- Demonstrate new or emerging technologies for use in high-tech buildings
- Partner with the SVLG and engage their high-tech member companies.
- Disseminate energy efficiency information to as wide an audience as possible.

Specific objectives for the various tasks are described below.

2.1 Cleanrooms and Laboratories

The objective of this task was to improve energy efficiency of cleanroom and laboratory facilities by executing selected high priority activities from the PIER high-tech buildings research roadmap as described below:

Task 2.1.1 Illustrate best practices identified in prior PIER projects

The objective of this task was to develop a case study to illustrate best practices that were previously identified in prior research activities. For this task a central chilled water plant at Sun Microsystems was studied.

Task 2.1.2 Research the feasibility for heat recovery from the low quality heat produced in high-tech buildings

Prior efforts to use waste heat generated by IT equipment or other high-tech processes have been hampered because of the relatively low temperatures produced. Direct use of Adsorption or Absorption chillers in typical high-tech buildings has generally not been adopted due to operational problems. The objective of this task was to research known low grade heat recovery methods that could be applicable for use in high-tech buildings.

Task 2.1.3 Develop energy criteria to be proposed for LEED™ certification of cleanroom facilities

For this task, LBNL collaborated with International Sematech, the semiconductor manufacturers' association in Austin, Texas. International Sematech was interested in developing Environmental Performance Criteria similar to that developed by LBNL for laboratory facilities. The objective of this task was to develop proposed criteria for use in obtaining LEED™ ratings for Semiconductor facilities and submitting this criteria to the US Green Building Council (USGBC) for their consideration for use on this building type. Such a criteria is desirable since the existing LEED™ criteria developed for commercial buildings does not adequately address the importance of the energy intensive nature of these facilities.

2.2 Data Centers

Similar to the cleanroom and laboratory tasks, the objective of the data center tasks was to perform high priority research as identified in the PIER "Data Center Energy Research Roadmap" to develop solutions that could lead to 40 percent or more energy efficiency improvement. The objectives for the data center activities are detailed below:

Task 2.2.1 Develop criteria to be proposed for LEED™ type certification of data centers

Similar to the task to develop criteria for use with cleanroom facilities, this task focused on the unique requirements for data center facilities. Currently the U.S Green Building Council's LEED™ certification program uses a point based system which assigns points for various sustainable design criteria. This point system was developed primarily to apply to commercial buildings to acknowledge sustainability. This criteria does not adequately reflect the importance of energy and water use in energy intensive data center facilities yet there is a desire by industry to apply the LEED™ criteria to data center facilities. The objective of this task was to develop draft criteria in collaboration with data center industry associations to ensure broad consensus for the recommended criteria. The draft criteria were to be submitted to the USGBC for their consideration.

Task 2.2.2 Evaluate modular and scalable cooling system concepts

The objective of this task was to assess the thermal and energy performance of commercially available modular cooling systems used for cooling racks of computers in data centers.

The design of traditional ventilation and cooling systems for data centers are typically less than optimal. Many manufacturers are now offering alternative cooling solutions that provide supplemental cooling in racks or rows of systems. Such pre-engineered systems could be a significant improvement over current design practice; however, without an energy focus, they could also lead to even lower energy efficiencies. This task evaluated four cooling products offered by four different manufacturers – APC, Emerson-Liebert, Rittal, and IBM – Vette and Sun Microsystems provided support for the evaluation in their data center in Santa Clara, CA.

Task 2.2.3 Encourage use of air economizers in data centers by investigating failure mechanisms

The objective of this task was to encourage the use of air economizers in data centers by overcoming barriers to the use of outside air. Air economizer cycles, which bring in large amounts of outside air to cool internal loads when weather conditions are favorable, as they are in many California climates, could save energy for cooling. However, there is reluctance from many data center operators to use this common cooling technique due to fear of equipment damage from introducing outside air pollutants which over time could cause equipment failures. The objective of this task was to provide additional understanding of the nature of equipment failures and if adverse effects are discovered, explore ways to mitigate them. Data center operators may be willing to incur increased contamination if greater information on the type and propensity of failures caused by pollutants were available.

2.3 Cross-cutting Efficiency Measures

This task included developing guidelines and strategies for crosscutting efficiency measures applicable to a variety of high-tech facilities. The objectives of these tasks were:

Task 2.3.1 Develop guidelines and training materials to achieve low pressure drop systems

The objective of this task was to develop guidelines for achieving a low pressure drop design. A key design consideration for gaseous and liquid systems is overall system pressure drop - or its resistance to flow. Guidelines illustrating how this can be achieved and highlighting this key design consideration can be used in various high tech facilities to achieve energy savings. The overarching objective of this task was to provide information to enable reduction in fan and pumping energy in high-tech buildings.

Task 2.3.2 Develop and update "Best Practices"

The objective of this task was to develop additional best practice information to supplement the best practices developed during the prior PIER high-tech buildings research. Ten Best Practices were developed and documented during the 2003-2007 PIER project addressing various high value topics. Two additional best practices – electrical distribution efficiency and variable speed pumping – were developed. These best practices can be used by high-tech industries to improve overall facility efficiency.

Task 2.3.3 Investigate strategies to promote commissioning

The objective of this task was to promote the use of commissioning for high-tech buildings. Commissioning records for high-tech buildings were to be examined to illustrate the value of commissioning to the high-tech community.

2.4 Demonstration Projects

The objective of this task was to perform two demonstrations of new or underutilized technology, and to identify other technologies for future demonstration projects by collaborating with the SVLG.

The first activity was to continue efforts promoting the use of direct current (DC) power in data centers by working with the Electric Power Research Institute (EPRI) and interested industry participants. Three specific objectives were targeted: 1. Develop a consensus of the DC voltage to be distributed within data centers. 2. Encourage development of standard connectors (similar to air-condition line cords today) and 3. Develop one or more pilot installations in real data center environments.

The second demonstration involved alternative cooling for IT equipment. For this demonstration, a technology developed by Spraycool, Inc. to cool heat intensive servers was demonstrated at Sun Microsystems in Santa Clara, CA. The objective of this demonstration was to perform a comparison between a rack of traditionally cooled servers compared with a rack that had been modified using the Spraycool technology. For this demonstration, Sun Microsystems provided the servers and the location for the demonstration in their Santa Clara, CA data center.

LBNL also investigated other technologies that could be appropriate for PIER demonstration projects. The objective was to select new or underutilized technologies and arrange industry partners that would participate in demonstrations.

During the term of this contract, the SVLG initiated a broader demonstration program by encouraging its member companies to demonstrate new or underutilized technologies.

The PIER sponsored modular cooling evaluation (Task 2.2.2) and the Spraycool demonstration were included in the SVLG group of demonstration projects. The broad objective of the SVLG program was in alignment with the PIER demonstration tasks. This was meant to encourage adoption of energy saving technologies through a public exchange of results. A further objective was to show how improvements suggested in Environmental Protection Agency's (EPA) report to Congress could be obtained using available solutions today.

2.5 Technology Transfer

The objective of the technology transfer activities was to convey the knowledge gained, the experimental results, and the lessons learned to key decision-makers in the various industries and institutions involved with high-tech buildings. Targeted audiences included facility designers and operators, manufacturers and suppliers, utilities, policy makers, and other public interest organizations.

CHAPTER 3:
Project Approach

The approaches for the cleanrooms and laboratories tasks were as follows:

3.1 Cleanrooms and Laboratories

Task 3.1.1 Illustrate best practices identified in prior PIER projects

This task was to develop a case study to illustrate one of the best practices that were previously identified in prior research activities. For this task the central chilled water plant at Sun Microsystems' Santa Clara campus was studied. Central chilled water systems are typically used in larger high-tech facilities yet their efficiency varies. Prior best practices studies identified strategies to achieve highly efficient systems. The Sun Microsystems' central chilled water plant was a relatively new design and was thought to be energy efficient. For this task, the chilled water system performance was determined by accounting for all of the energy use in the system including all fans, pumps, chillers and associated equipment. This, along with flow measurement, enabled a determination of the kilowatt/ton performance for the whole system. Tons of cooling is a commonly used measure of the amount of cooling provided. KW/ton is commonly used as the energy metric to evaluate the efficiency of the cooling plant. The system was also reviewed to see which best practices were utilized and recommendations were made which would enable greater energy savings.

Task 3.1.2 Research the feasibility for heat recovery from the low quality heat produced in high-tech buildings

Limited research into existing techniques for recovery of heat from low-grade sources was conducted. This review confirmed that the current heat recovery technologies are not likely to be economically applied to data centers. However, using waste heat directly to heat adjacent spaces or other non-conventional uses may be feasible. For example, LBNL investigated the use of waste heat from supercomputers to heat adjacent office spaces. In this specific application it was determined to be feasible through the use of "run-around" coils to transfer the heat. A further investigation into use of the heat given off by the computers to heat adjacent laboratory buildings using runaround coils was undertaken. Other uses of waste heat have been described in the press including use of waste heat-to-heat swimming pools, district heating systems, and greenhouses. It is possible in the future that other innovative uses of waste heat will be determined. Due to the unlikely success in discovering or developing new low-grade heat uses, this activity was terminated.

Task 3.1.3 Develop energy criteria to be proposed for LEED™ certification of cleanroom facilities

For this task, LBNL collaborated with Sematech, the semiconductor manufacturers' association in Austin, Texas. Sematech was interested in developing Environmental Performance Criteria for cleanrooms similar to that developed by LBNL for laboratory facilities. The approach for this task was to collaborate directly with the Sematech team. The previously developed criteria for laboratories were used as a starting point for the cleanroom criteria since there are many similarities in the two building types. The industry team which included Sematech member companies developed proposed criteria for use in obtaining LEED™ ratings for Semiconductor facilities. This criteria was then discussed with the US Green Building Council (USGBC) and subsequently submitted for formal consideration.

3.2 Data Centers

The approaches for the data center tasks were as follows:

Task 3.2.1 Develop criteria to be proposed for LEED™ type certification of data centers

To develop a proposed set of criteria for use in LEED™ certification of data centers, a working group was developed which included representatives from all of the major data center industry associations. This working group included representatives from Silicon Valley Leadership Group, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) TC 9.9, the Uptime Institute, the Critical Facilities Roundtable, Green Grid, and 7x24 Exchange. The approach involved first developing a draft set of criteria through a small group of industry experts and then disseminating this draft for formal review by the various organizations. Through a series of meetings and conference calls, proposed criteria were developed that provided increased emphasis on sustainable issues important to data centers – primarily energy and water use. The draft criteria was then reviewed and commented on by a large number of data center stakeholders. Comments were incorporated and a finalized draft criteria document was submitted to the US Green Building Council for review.

Task 3.2.2 Evaluate modular and scalable cooling system concepts

The approach in evaluating modular cooling systems was developed in conjunction with the manufacturers of the equipment and Sun Microsystems. Sun initially had two different modular systems installed in its Santa Clara Data Center – high density in-row cooling solutions from American Power Conversion (APC) and Emerson/Liebert. They agreed to have LBNL act as a third party reviewer and conduct performance measurements on the installed units. When two other vendors – Rittal and IBM-Vette learned of the evaluation, they offered to provide their equipment for evaluation and Sun agreed to host the testing and also provided servers to populate the racks for testing. The industry partners worked collaboratively to define the testing protocol which included taking power and temperature measurements at various loading conditions. The team was assisted by Power Assure Inc. who helped ensure that each test was loaded in a similar manner, and by Modius who assisted in data collection. Individual test reports were prepared for each of the systems.

Task 3.2.3 Encourage use of air economizers in data centers by investigating failure mechanisms

The approach for this task was to quantify particulate contamination by measuring particle concentrations in an operating data center using various filters. NetApp in Sunnyvale, CA agreed to host the experiments.

Particle concentrations were measured at the NetApp data center with an air economizer in operation while using filtration of varying levels of efficiency. Three different types of heating, ventilating, and air conditioning (HVAC) filters were installed during the monitoring period. Immediately before the monitoring period, new air filters with a Minimum Efficiency Reporting Value (MERV) of seven were installed. These are the filters commonly used at this data center. Previous studies have observed that MERV 7 filters are common to most data centers. During the monitoring period, the MERV 7 filters were removed and replaced with MERV 11 filter, and then again replaced with MERV 14 filters. The increased MERV rating indicates greater efficiency of particle removal by the filter. Particle concentrations were measured and documented under each filtration type for both active and inactive economizer use.

Information regarding data center power demand was gathered from the energy management control system (EMCS) during the same period as particle monitoring. Life-cycle costing of each filtration scenario was performed to also address initial cost, maintenance, and filter life.

The findings were then summarized for inclusion in this report.

3.3 Cross-cutting Efficiency Measures

For this task several cross-cutting efficiency measures and strategies were documented that have applicability to laboratories, cleanrooms, and data center facilities. The approach was to document the principles involved for three important cross-cutting areas. The approaches for each of these tasks were:

Task 3.3.1 Develop guidelines and training materials to achieve low pressure drop systems

The approach to developing this guide was to draw upon the lessons learned by observing best practices in prior case studies and benchmarking activities. The practices that resulted in energy efficient performance were noted along with practical design experience from leading energy design firms.

Task 3.3.2 Develop and update "Best Practices"

The approach for this task was to develop detailed written guidelines for additional best practices from those observed during prior PIER high-tech buildings research in order to have a more complete set of guidance. Previously, several high value topics were documented and this task was to further develop this information. For this task, electrical distribution, and variable speed pumping systems were described.

Task 3.3.3 Investigate strategies to promote commissioning

The approach for this task was to review the DOE report that developed a framework for characterizing buildings and evaluated the cost effectiveness of energy-oriented commissioning. Included in this review was a subset of high-tech facilities. Data from this study illustrates the value of commissioning and can be used to justify commissioning activities.

3.4 Demonstrations of New or Underutilized Technologies

This task was primarily to promote new or underutilized technologies. The approach for this task was to continue involvement with the Silicon Valley Leadership Group to encourage their member companies to participate in demonstration projects. This involved periodic phone conferences and meetings to develop projects, and plan for a yearly workshop to showcase the completed demonstrations. This planning led to a large number of industry demonstrations of various technologies that were shared amongst the workshop participants and the public at large.

Two additional specific technologies were suggested for demonstration under the PIER program. One involved use of wireless sensor technology to monitor data center conditions and directly control computer room air handlers. The second involved using sensors in IT equipment to directly control computer room air handlers.

This task also involved continuation of a previous PIER demonstration to promote the use of DC power distribution in data centers. The work was supported by a broad group of industry participants that had participated in the earlier proof of concept demonstration. In this phase, a workshop was held to summarize progress to date; to attempt to reach consensus on standard electrical distribution voltages; and to encourage development of standard connectors. The approach also included efforts to arrange for pilot installations in operating centers. LBNL's subcontractor, the Electric Power Research Institute led the DC power tasks. Regular phone meetings with the industry participants were held to review activities in these areas and seek input on demonstration opportunities.

Several industry demonstrations were pursued. The approach was to find an industry partner who was interested in becoming an early adopter for this technology. Several potential projects were identified including:

- Sonoma Mountain Village – a new data center project in Sonoma, Ca that is seeking to develop a sustainable community. A pilot project would depend upon the center's customer's acceptance once the facility was completed. Although this may occur eventually, it was not able to be accomplished during the contract period.
- Equinix – Equinix, a co-location facility in San Jose, expressed interest in pursuing DC power and several scoping meetings were held. Ultimately they did not proceed with the demonstration.
- AT&T – AT&T has expressed interest in a pilot demonstration in their Hayward, CA test bed facility. Although it was hoped that this demonstration could occur during this contract period, market events dictated that this be delayed.
- Nippon Telegraph and Telephone (NTT) America – NTT America initially expressed interest in housing a DC pilot demonstration within a portion of a new data center under construction. After several meetings and discussions, NTT management decided not to pursue a project in the US at this time although NTT is proceeding with a DC center in Japan.

- UC San Diego – UCSD is planning to install DC infrastructure to support existing and planned renewable on-site energy sources. LBNL and UCSD have had several planning meetings to plan for the inclusion of a DC power pilot demonstration for some of their computing resources on site. There is now a commitment to proceed with this demonstration and the UC has provided letters of commitment in support of the project. The project would have been completed beyond the term of this contract and was proposed for follow-on under a new contract.

A second demonstration involved evaluation of an alternative cooling technology developed by SprayCool. This technology is based upon cooling by directly spraying a dielectric fluid onto hot electronic components. The fluid is contained and undergoes phase changes in order to exchange heat. The approach in this demonstration was to compare the cooling effectiveness to standard practice. Sun Microsystems provided the servers for the demonstration as well as space in their Santa Clara, CA data center. Energy performance was monitored while the computer systems were operating in a controlled manner. The results were then compiled for inclusion in this report.

3.5 Technology Transfer

The approach to technology transfer activities was to utilize as many channels of communication as possible, with efforts tailored for distinct target audiences, in order to reach the largest number of stakeholders. This included:

- An extensive website where detailed technical information was presented and continuously updated and maintained
- Periodic newsletters distributed to large audiences
- Trade publications
- Video documentaries
- Journal articles
- Workshops with industry
- Collaboration with industry associations and professional societies
- Interim reports of findings
- Best Practice summaries
- Utility workshops/training
- Individual requests for information
- Interaction with PIER
- Industry press releases

CHAPTER 4: Project Outcomes

Project findings for each task are summarized below and detailed task reports and related information is provided as appendices to the report.

4.1 Cleanrooms and Laboratories

The outcomes for the cleanrooms and Laboratories tasks are as follows:

Task 4.1.1 Illustrate best practices identified in prior PIER projects

To illustrate one of the best practices identified in prior PIER research, the chilled water plant at Sun Microsystems was studied. The case study of this facility is attached as Appendix A. The findings from this study include:

- Chilled water system efficiency = 0.52 kW/ton
- Variable speed drives for cooling tower fans, condensate pumps, chilled water pumps and chillers contributed to the efficiencies observed
- Delta T for the system was better than average but could have been higher for further efficiency gain

Although this chilled water plant was a relatively efficient design, further efficiency opportunities were observed. These included:

- Raising chilled-water supply temperature to 70°F thereby reducing the total plant kW/ton significantly.
- Adding an integrated waterside economizer to the chilled water return line upstream of the chillers.
- Resetting the supply temperature by demand. A higher supply temperature would need to accommodate office space as well.
- Resetting condenser water temperature with pump speed, which would yield an estimated 20-30 percent chilled water plant savings. Control sequence would be to slow pump speed while increasing tower fan speed, providing the effect of a larger tower.
- Reduce minimum speeds for the cooling tower fans to 6hz from 20hz.

Task 4.1.2 Research the feasibility for heat recovery from the low quality heat produced in high-tech buildings

The conclusions from this task were that low-grade heat (low temperatures) produced through the processes and infrastructure of high-tech buildings is difficult to capture and convert to a useful purpose. Somewhat higher temperatures can be used economically to drive adsorption or absorption chillers or other heat recovery systems however the relatively low temperatures for waste heat in laboratories, cleanrooms, and data centers typically does not support economical heat recovery.

Complicating the issue is the fact that many laboratory and cleanroom facilities exhaust streams contain hazardous materials which must not be reintroduced into the buildings. There have been attempts at heat recovery through heat wheels or other indirect heat transfer. Significant barriers including finding materials that can effectively withstand harsh environments limit the widespread adoption of heat recovery.

There have been some innovative uses of waste heat from data centers, however. Heat recovery schemes involving heating adjacent office spaces, swimming pools, district heating systems, or greenhouses have been publicized. Some have suggested locating data centers adjacent to laundries. Both LBNL and the National Renewable Energy Laboratory (NREL) are investigating use of waste heat in adjacent office or laboratory spaces by either direct use of the heated air or through run-around coils to transfer the heat. In colder climates use of waste heat to heat office or other production spaces may be more economically viable. While it is logical and promising to look for uses for the waste heat produced in high-tech buildings, there presently are few opportunities that are economically viable. This may change as higher temperature air or liquid is produced in high density data centers.

Following the preliminary investigation, this task was terminated. Due to the difficulty in developing new low-grade heat uses, this activity was not studied further.

Task 4.1.3 Develop energy criteria to be proposed for LEED™ certification of cleanroom facilities

For this task, LBNL collaborated with Sematech, the semiconductor manufacturers' association in Austin, Texas. The outcome of this task was development of draft criteria for modified LEED™ criteria which is more applicable to the unique attributes of cleanroom and semiconductor manufacturing facilities. The industry team which included Sematech member companies developed proposed criteria – termed Environmental Performance Criteria for use in obtaining LEED™ ratings for Semiconductor facilities. These criteria were submitted to the US Green Building Council (USGBC) formal consideration. The draft criteria is attached in Appendix C.

4.2 Data Centers

Task 4.2.1 Develop criteria to be proposed for LEED™ type certification of data centers

The outcome of this task was a new draft LEED™ criteria for evaluating data centers (for new construction). The criteria were developed and reviewed by a working group which included representatives from all major data center industry associations. This working group included representatives from Silicon Valley Leadership Group, ASHRAE TC 9.9, the Uptime Institute, the Critical Facilities Roundtable, Green Grid, and 7x24 Exchange. The draft criteria thus represented a consensus of the industry for criteria important to data centers. The draft criteria included increased emphasis on sustainable issues important to data centers – primarily energy and water use. The draft criteria document was submitted to the US Green Building Council for review. The draft criteria are attached as Appendix D.

Task 4.2.2 Evaluate modular and scalable cooling system concepts

The outcome of the evaluations of modular cooling systems was a better understanding of the operation of modular cooling systems. Four systems were evaluated and individual reports on the performance of each system are attached as Appendix E.

In many ways the systems were significantly different and did not lend themselves to direct comparisons. Although it was difficult to develop "apples to apples" comparisons there were some general conclusions from the study:

- All of the systems adequately cooled the racks of computers provided for the study.
- Due to the equipment provided by Sun Microsystems for the testing, high intensity heat loads were not developed so ultimate capability or performance at high density was not tested
- Some of the modular systems' controls had difficulty controlling temperatures to desired values.
- Modular systems do have potential to improve efficiency over current practice however other designed systems could be designed to perform as well or better.
- Passive systems (without additional fans, pumps, etc.) can be energy efficient.
- Modular systems can enable use of higher temperature cooling water since air recirculation is eliminated (or minimized) and achieve higher temperature differences (delta T) which enables cooling coils to operate more efficiently.
- Modular systems in part can contribute to an effective strategy to incrementally build out a data center.

LBNL provided third party verification of the systems tested. The LBNL goal was primarily to see if Modular Systems had the ability to improve overall efficiency and was not focused on comparing performance of one unit to another.

Task 4.2.3 Encourage use of air economizers in data centers by investigating failure mechanisms

The outcome of this task was the measurement of particle concentrations and corresponding energy use in an operating data center using various filters installed in their air handlers that were equipped with economizers. NetApp in Sunnyvale, CA hosted the experiments.

Particle concentrations were measured at the NetApp data center which was equipped with an air economizer. Measurements were taken in operation using filtration of varying levels of efficiency. Three different types of HVAC filters were installed during the monitoring period. Immediately before the monitoring period, new air filters with a Minimum Efficiency Reporting

Value (MERV) 7 were installed. These are the filters commonly used at this data center and in many commercial buildings. Previous studies have observed that MERV 7 filters are common to many data centers in California. During the monitoring period, the MERV 7 filters were removed and replaced with MERV 11 filters (better filtration), and then again replaced with MERV 14 filters (even better filtration). The increased MERV rating indicates greater efficiency of particle removal by the filter. Particle concentrations in the data center were measured and documented under each filtration type for both active and inactive economizer use.

Information regarding data center power demand was gathered from the energy management control system (EMCS) during the same period as the particle monitoring. Life-cycle costing of each filtration scenario was performed to also address initial cost, maintenance, and filter life.

The study concluded that normal building filtration should meet manufacturers' contamination guidelines. Improved filtration provided even better cleanliness with a slight overall energy impact. Centers desiring to use better filtration when using air economizers can realize large energy savings compared to traditional "closed" data centers even though small increases in fan energy may be required. The full report is attached as Appendix F.

4.3 Cross-cutting Efficiency Measures

For this task a guideline and best practices were developed for strategies that have applicability to laboratories, cleanrooms, and data center facilities. A report on Commissioning documenting the benefits of this practice is also included.

Task 4.3.1 Develop guidelines and training materials to achieve low pressure drop systems

This guide was developed by drawing upon the practices observed in prior case studies and benchmarking that resulted in energy efficient performance and the design experience from leading energy design firms. The guide is attached as Appendix G.

Task 4.3.2 Develop and update "Best Practices"

Previously, several best practice topics were documented. For this task, electrical distribution, and variable speed pumping systems were described. The best practice descriptions are attached as Appendix H.

Task 4.3.3 Investigate strategies to promote commissioning

A report documenting the review of commissioning outcomes was prepared and is attached as Appendix I.

4.4 Demonstrations of New or Underutilized Technologies

This task continued collaboration with the Silicon Valley Leadership Group who encouraged their member companies to participate in demonstration projects. This involved periodic phone conferences and meetings to develop projects, and plan for a yearly workshop to showcase the completed demonstrations. This planning led to a large number of industry demonstrations of various technologies that were shared amongst the workshop participants and the public at large.

Two additional specific technologies were suggested for demonstration under the PIER program. One involved use of wireless sensor technology to monitor data center conditions and directly control computer room air handlers. The second involved using sensors in IT equipment to directly control computer room air handlers. The projects were approved by the Commission and were implemented under separate authorizations administered by the California Institute for Energy and Environment (CIEE).

This task also involved continuation of a previous PIER demonstration to promote the use of DC power distribution in data centers. The work was supported by a broad group of industry participants that had participated in the earlier proof of concept demonstration. In this phase, a workshop was held to summarize progress to date; to attempt to reach consensus on standard electrical distribution voltages; and to encourage development of standard connectors. The approach also included efforts to arrange for pilot installations in operating centers. LBNL's subcontractor, the Electric Power Research Institute led the DC power tasks. Regular phone meetings with the industry participants were held to review activities in these areas and seek input on demonstration opportunities.

Several industry demonstrations were pursued. The approach was to find an industry partner who was interested in becoming an early adopter for this technology. Several potential projects were identified including:

- Sonoma Mountain Village – a new data center project in Sonoma, Ca that is seeking to develop a sustainable community. A pilot project would depend upon the center's customer's acceptance once the facility was completed. Although this may occur eventually, it was not able to be accomplished during the contract period.
- Equinix – Equinix, a co-location facility in San Jose, expressed interest in pursuing DC power and several scoping meetings were held. Ultimately they did not proceed with the demonstration.
- AT&T – AT&T has expressed interest in a pilot demonstration in their Hayward, CA test bed facility. Although it was hoped that this demonstration could occur during this contract period, market events dictated that this be delayed.
- NTT America – NTT America initially expressed interest in housing a DC pilot demonstration within a portion of a new data center under construction. After several meetings and discussions, NTT management decided not to pursue a project in the US at this time although NTT is proceeding with a DC center in Japan.
- UC San Diego – UCSD is planning to install DC infrastructure to support existing and planned renewable on-site energy sources. LBNL and UCSD have had several planning meetings to plan for the inclusion of a DC power pilot demonstration for some of their computing resources on site. There is now a commitment to proceed with this demonstration and the UC has provided letters of commitment in support of the project. The project would have been completed beyond the term of this contract and was proposed for follow-on under a new contract.

Unfortunately, the DC power demonstration with one of these partners was not able to be scheduled within the term of this contract and the decision was made to postpone a demonstration until a later project.

The demonstration of alternative cooling involved SprayCool technology. This demonstration was completed at the Sun Microsystems facility in Santa Clara, CA.

4.5 Technology Transfer

The approach to technology transfer activities was to utilize as many channels of communication as possible, with efforts tailored for distinct target audiences, in order to reach the largest number of stakeholders. This included:

- An extensive website where detailed technical information was presented and continuously updated and maintained
- Periodic newsletters distributed to large audiences
- Trade publications
- Video documentaries
- Journal articles
- Workshops with industry
- Collaboration with industry associations and professional societies
- Interim reports of findings
- Best Practice summaries
- Utility workshops/training
- Individual requests for information
- Interaction with PIER
- Industry press releases

CHAPTER 5: Conclusions and Recommendations

5.1 Conclusions

High-tech industries continue to be extremely important to the California economy. Many High-tech firms are headquartered in California and represent most major sectors of the economy including biotech, semiconductor, aerospace, healthcare, etc. Energy use and intensity is large in these industries and continues to grow. As manufacturing has moved out of the State in some sectors (e.g. semiconductor mfg.) other high tech businesses have taken over the energy intensive facilities (e.g. solar panel or biotech. mfg.). The high energy intensity of these facilities often continues on in a new sector. Energy cost is becoming more visible to industry senior management and they are now more engaged in finding energy reduction strategies as evidenced by the large voluntary demonstration activity by SVLG. For data centers, which are prevalent throughout California, the cost of electricity now outweighs the capital cost of the IT equipment that it powers over the equipment's lifetime. Slowing the growth trend and hopefully eventually reducing overall data center power consumption can ease tight transmission and distribution capacity and delay the need for additional generation.

PIER leadership in this sector has been acknowledged and has encouraged synergistic activities at other industry associations and public interest organizations including New York State Energy Research and Development Authority (NYSERDA), Department of Energy- Efficiency and Renewable Energy (DOE-EERE), Department of Energy- Federal Energy Management Program (DOE-FEMP), Energy Protection Agency (EPA), and public utilities.

This project has provided further insight into the energy efficiency opportunity in cleanrooms, laboratories and data center facilities. The various technologies and demonstrations explored show that there is potential for large energy savings using best practices available today as well as improved performance with new solutions. Energy savings of 20-40 percent have been shown to be possible and this was re-affirmed by the Silicon Valley Leadership demonstrations. This project has also helped to raise the awareness of California data center operators and designers.

Specifically, the following conclusions can be drawn from this project:

- Case studies of best practices that have been implemented in high-tech buildings are an effective mechanism for illustrating the technologies and their benefits to a wide audience.
- Current technologies producing low-grade (low temperature) heat recovery from high-tech buildings have long pay back times. As energy intensities rise and as liquid cooling solutions are implemented, the recapture of waste heat should become more practical.
- Current LEED™ criteria implemented by the US Green Building Council do not place enough emphasis on the energy and water use that is typical in most high-tech

buildings. Proposed criteria developed under this project would provide more appropriate labeling criteria for these building types.

- Commercially available modular cooling solutions for data centers generally perform better than standard practice. Close coupling the cooling systems to the heat sources (racks of computers) results in improved efficiency since air mixing is eliminated allowing the cooling systems to operate at higher efficiency.
- Contamination in data centers due to particulates entering through air economizers can readily be controlled through effective filtration. Use of air economizers can greatly reduce the energy required for compressor based cooling resulting in large energy savings.
- Different types of high-tech buildings (laboratories, cleanrooms, data centers) have similar efficiency concerns. Low-pressure drop system design guidance, best practices, and commissioning practices are applicable to each building type.
- Demonstration of new or underutilized technologies is an effective way to accelerate adoption, avoid the "valley of death", and transfer the technologies to a wide number of high-tech building stakeholders. Developing demonstrations in conjunction with the Silicon Valley Leadership Group can leverage PIER projects to reach an important segment of California industries.
- Technology transfer is an important element in delivering the lessons learned through research and demonstrations. Through use of various communication channels (e.g. websites, workshops, training programs, industry contact) a large number of high-tech building stakeholders were reached.

5.2 Recommendations

Research opportunities identified in prior PIER research roadmaps should be reviewed and updated to reflect the rapid pace of high-tech innovation. Important energy efficiency opportunities should be pursued. Recommendations from this project continue to be in line with the original roadmaps' recommendations however the high-tech buildings' energy research roadmaps should be updated due to the rapid evolution in the sector. Specific recommendations include:

- Establish a High-tech Buildings Collaborative Research activity similar to California's Demand Response Center to accelerate progress in this area and leverage PIER activities with other potential funders.
- Continue market transformation activities to promote use of economizers (free cooling) in data centers should be continued.
- Best practices should continue to be developed and publicized through demonstrations and case studies for training and in order to promote wider adoption. Partnering with the Silicon Valley Leadership Group in an active role of facilitating and publicizing data

center demonstration projects and participating in a yearly data center summit should continue.

- New and emerging data center cooling solutions such as the Clustered Systems solution should be evaluated in order to determine their energy implications. Demonstrations or incentives should be explored in order to encourage use of solutions that offer the most efficient operation.

- Direct use of DC power in data centers continues to hold promise for substantial energy savings in data centers while improving reliability and reducing capital cost. Continued encouragement of the technology through demonstrations and incentives could speed its adoption.

- Power distribution efficiency within data centers and other high-tech facilities should continue to be a major focus for research, best practice identification, and outreach. Efficiencies of various power distribution designs utilizing AC or DC power should be studied. Collaborations with industry organizations such as Green Grid, IEEE, and others should be established to help identify energy efficient schemes and evaluate performance of their power conversion devices.

- Opportunities for heat recovery and reuse should continue to be explored and publicized. As heat intensities rise, there will be more opportunity to reuse the heat that is currently rejected to atmosphere. Creative energy reuse schemes should be publicized in case studies or demonstration projects.

GLOSSARY

Specific terms and acronyms used throughout this work statement are defined as follows:

ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
BTU	British Thermal Unit
Cfm	cubic feet per minute, a measure of ventilation rate
Commission	California Energy Commission
CPR	Critical Program Review
DOE	United States Department of Energy
GW	Gigawatt (1×10^9 Watt)
HVAC	Heating, ventilation, and air conditioning system
IT	Information Technology
KW	Kilowatt (1000 Watts)
LBNL	Lawrence Berkeley National Laboratory
MW	Megawatt (1×10^6 Watt)
PAC	Project Advisory Committee
PIER	Public Interest Energy Research program (Commission)
RD&D	Research, Development and Demonstration
T	Temperature, measured in degrees Celsius or Fahrenheit
TC	Technical Committee
TWh	Terrawatt hour (1×10^9 kWh)
UPS	Uninterruptible Power Supply

REFERENCES

A complete list of publications produced under this project, as well as reports referencing the work can be found here: http://hightech.lbl.gov/library.html

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